STATUS OF THE MINOS EXPERIMENT

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Abstract. The MINOS Experiment is in operation since March 2005, having collected NuMI beam data of about 1×10^{20} POT. In parallel, atmospheric neutrino and antineutrino interactions are being collected steadily since August 2003. In this talk the physics goals of the MINOS experiment are presented along with a description of the NuMI beam and MINOS detectors. First results from fully and partially contained atmospheric ν_μ and $\overline{\nu}_\mu$ interactions in the far detector, as well as the current status of beam data collection and analysis are presented.

THE MINOS EXPERIMENT

The MINOS experiment [1] was designed to make a precise study of the neutrino oscillations observed in recent data from underground experiments with "atmospheric" neutrinos, and also accelerator neutrinos [2]. The primary goal of the MINOS experiment is to demonstrate the oscillatory behavior of the neutrino flux, by measuring and comparing the neutrino energy spectrum from charged current (CC) ν_μ interactions between the near and far detectors, and to make a precise determination of the oscillation parameters. MINOS expects to measure Δm^2 to about 10%. In addition, MINOS will search for $\nu_\mu \rightarrow \nu_e$ oscillations and attempt a first measurement of $|U_{e3}|$.
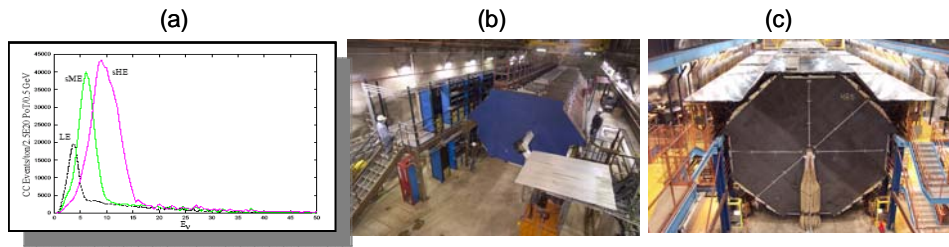

FIGURE 1. a) Energy tunes of the NuMI beam b) MINOS Near Detector c) MINOS Far detector.

The MINOS Far detector is the only large underground detector with a magnetic field. This will make possible a comparison of survival probabilities between ν_μ's and $\overline{\nu}_\mu$'s. Here we present first results of such measurements [3], along with the current status of data collection and analysis with neutrinos from the NuMI beam. The NuMI beam is described in some detail in Ref. [4]. The experiment uses neutrinos

produced in the NuMI beamline by 120 GeV protons (currently 2.5 s cycle time, 2.5×10^{13} ppp) from the new Main Injector at Fermilab, in a fast extraction mode (10 µs). A two-magnetic horn system, focusing pions and kaons, followed by a 675 m long decay pipe and muon absorber, produces a ν_μ beam of tunable energy spectrum (Fig. 1a). The construction and commissioning of the NuMI beam was completed in March 2005. MINOS uses two detectors [1, 5] with a mass of 980 ton and 5400 ton, located at distances of 1 km and 735 km from the neutrino source, respectively (Figs. 1b,c), with the same basic structure of a segmented iron-scintillator calorimeter and magnetized muon spectrometer. The Far and Near detector assembly and commissioning was completed in August 2003 and Fall 2004, respectively. The design of the MINOS detectors allows for adequate tracking for both detectors, and good timing of $\sigma \approx 2.3$ ns per single hit, for the Far detector. Muon momentum measurement is done with muon range and curvature. Rejection of cosmic rays in the far detector is accomplished with a veto shield on the top and sides of the detector. These detector capabilities make it possible to classify neutrino interactions, measure neutrino energy, determine particle direction, identify up/down going muons, and separate ν_μ from $\bar{\nu}_\mu$ interactions.

ATMOSPHERIC NEUTRINOS

We have collected 418 live days of fully contained (FC) and partially contained (PC) atmospheric neutrino interactions, corresponding to 6.18 Kt-years (fiducial 4.54 Kt-years). We use timing, tracking, and magnetic field, to classify these events as up/down, ν_μ / $\bar{\nu}_\mu$ interactions. Details of this analysis are given in Ref. [3]. After a series of cuts, we end up with 107 events out of which 77 have good timing and are used in the subsequent analysis. The zenith angle distribution is shown in Figure 2a, along with Monte Carlo predictions with and without oscillations.
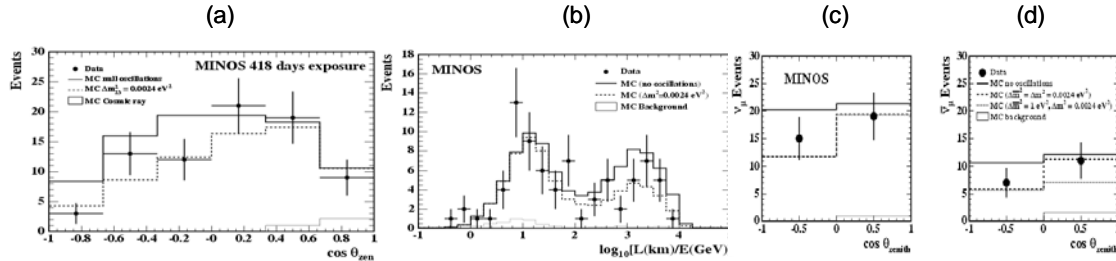

FIGURE 2. Analysis of 77 ν_μ (and $\bar{\nu}_\mu$) interactions with good timing, and comparison with MC expectations without and with oscillations with $\Delta m^2_{23} = 2.4 \times 10^{-3}$ eV^2, assuming full mixing: a) zenith angle distribution b) L/E distribution c) and d) zenith angle distributions of 34 (18) unambiguous ν_μ ($\bar{\nu}_\mu$) interactions and comparison with MC expectations without and with oscillations, assuming that ν_μ's and $\bar{\nu}_\mu$'s oscillate with the same parameters. Comparison is also shown with $\bar{\nu}_\mu$'s oscillating with $\Delta m^2_{23} = 1.0$ eV^2.

From this data and background analysis we determine the up/down double ratio of data to Monte Carlo to be: $0.62^{+0.19}_{-0.14}$ (stat) $\pm$ 0.02 (sys), with the MC generated without oscillations. This result is about 2σ away from unity. Fitting the reconstructed L/E distribution (Fig. 2b) with $\nu_\mu \rightarrow \nu_\tau$ oscillation hypothesis, using an extended

maximum likelihood analysis, which takes into account the different L/E resolutions on an event-by event basis, we exclude the null hypothesis of no neutrino oscillations at the 98% level [3]. The magnetic field of the MINOS far detector allows for the study of ν_μ vs $\bar{\nu}_\mu$ disappearance. The selected contained events with unambiguous timing information are classified into 34 ν_μ and 18 $\bar{\nu}_\mu$ interactions on the basis of the reconstructed muon charge [3], giving a $\bar{\nu}_\mu/\nu_\mu$ ratio of $0.53^{+0.21}_{-0.15}$ (stat) $\pm$ 0.03 (sys). Assuming that ν_μ's and $\bar{\nu}_\mu$'s oscillate with the same parameters we can estimate the data/MC ratio of ratios to be $0.96^{+0.38}_{-0.27}$ (stat) $\pm$ 0.15 (sys). This is the first direct observation of atmospheric neutrino interactions separately for ν_μ's and $\bar{\nu}_\mu$'s. Their zenith angle distributions are shown in Figs. 2c,d, in comparison with MC expectations without and with oscillations. The data seem consistent with ν_μ's and $\bar{\nu}_\mu$'s oscillating with the same parameters. However, with the present statistics, our data do not exclude CPT violating scenarios with large values of Δm^2_{23} for $\bar{\nu}_\mu$'s.

ACCELERATOR (NUMI BEAM) NEUTRINOS

Upon completion of the commissioning of the NuMI beam in March 2005, MINOS started collecting data from neutrino interactions in both detectors. The present beam intensity is about 2.7×10^{13} protons on target (POT) per spill, at a repetition rate of a little over 2 sec, and a spill size of 8-10 μs. At the time of writing this report the collected data corresponds to over 1×10^{20} POT. Fig. 3a shows the time evolution of data collection. Fig. 3b shows the activity in the near detector for a single beam spill in the high energy beam configuration. Figs. 3c,d shows two longitudinal views of a 14.7 GeV CC neutrino interaction in the MINOS Far detector.
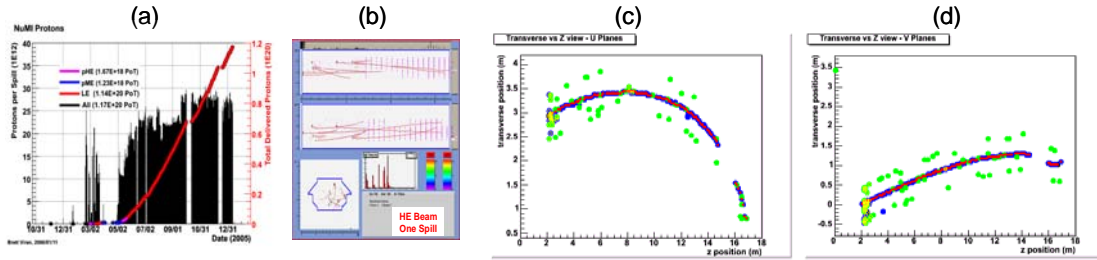
FIGURE 3. a) Time evolution of NuMI beam intensity and integrated intensity (red) b) Near detector activity during a single spill; shown are 3 views and a timing plot; several neutrino interactions are visible; separation is done via time clustering (time slicing) of detector hits. c) x-z projection of a muon track in the far detector; the neutrino beam comes from the left, where a vertex is visible. The track break is due to the dead space between the two supermodules. d) y-z projection of the same track.

Analysis for both data and Monte Carlo has proceeded at a fast pace. It should be noted that we perform a blind analysis for the far detector. Only a fraction of the far detector events are available for analysis and comparison with Monte Carlo. Figs. 4a,b show the pulse height per plane for reconstructed muons in both detectors, and good agreement in comparison with the Monte Carlo. The neutrino event identification in the far detector is accomplished by using timing and topological characteristics of the expected neutrino interactions. Fig. 4c shows the time distribution of neutrino interactions in the far detector for the non-blinded sample. This timing is consistent

with the 10 μs duration of the beam spill. Similarly, Fig. 4d shows the vertex x-y distribution in the far detector. The data analysis is showing that the event characteristics are in agreement with expectations. Results from the analysis of the already recorded data, corresponding to about 1×10^{20} POT, are expected in 2006. Monte Carlo expectations for longer MINOS running have been presented in Ref. [5].
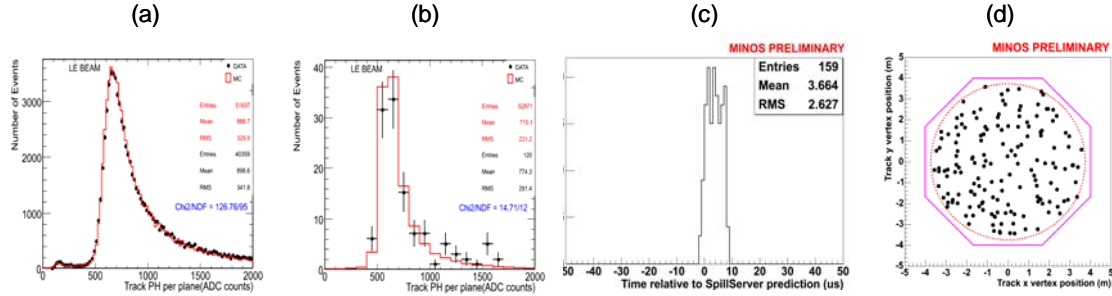
FIGURE 4. a) Pulse height per plane for reconstructed muon tracks in the Near detector compared to MC. b) Same for the Far detector; c) Timing distribution for neutrino interactions in the Far detector (non-blinded sample); events happen during a 10 μs spill. d)Vertex x-y distribution in the Far detector (non-blinded sample).

In conclusion, the MINOS experiment is performing well in collecting NuMI beam neutrino interactions, as well as atmospheric ν_μ and $\bar{\nu}_\mu$ interactions. We have presented first results of atmospheric FC and PC ν_μ and $\bar{\nu}_\mu$ interactions, which are in agreement with previous experiments. Within the low statistics the data are consistent with ν_μ's vs $\bar{\nu}_\mu$'s oscillating with the same parameters. The NuMI beam intensity is steadily improving, and both detectors are operating satisfactorily. The Near detector is accumulating high statistics data, while blind analysis is applied to the Far detector data. First results from NuMI beam neutrinos are expected in 2006.

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REFERENCES

(†) MINOS is an International Collaboration of 175 physicists from 32 Institutions from Brazil, France, Greece, Russia, UK, and USA.

1. Fermilab Proposal P875, February 1995. The MINOS Technical Design Report, Fermilab, **NUMI-L-337**, October, 1998.

2. Y. Fukuda et al., PRL **81**, 1562 (1998); S. Fukuda et al., PRL **85**, 3999 (2000); M. Ambrosio et al., Phys. Lett. **B434**, 451 (1998), hep-ex/9807005; M. Ambrosio et al., Phys. Lett. **B478**, 5(2000), hep-ex/0001044; W.W.M.. Allison et al., Phys. Lett. **B449**, 137 (1999), hep-ex/9901024; D.A. Petyt et al., Nucl. Phys. Proc. Suppl. **110**, 349 (2002); Y. Ashie et al.,PRL **93**:101801 (2004), hep-ex/0404034; Y. Ashie et al., Phys. Rev**. D71**:112005 (2005), he-ex/0501064 and references therein; E. Aliu et al. PRL **94**: 081802 (2005) and references therein.

3. P. Adamson et al., hep-ex/0512036/15 Dec 2005, submitted to Phys. Rev. D.

4. J. Hylen *et al.*, "NuMI Facility Technical Design Report," Fermilab-TM-2018, Sept., 1997; S. Kopp,"The NuMI Neutrino Beam at Fermilab", Fermilab-Conf-05-093-AD.

5. D. Michael, (NEUTRINO 2002), Nucl. Phys. B (Proc. Suppl.) **118**, 189(2003); M. V. Diwan (MINOS Collaboration), (TAU 02) Nucl. Phys. B (Proc. Suppl.) **123**, 272(2003), hep-ex/0211026, G. Tzanakos (MINOS collaboration), (NUFACT03), **AIP 721**, 179 (2004).